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Introduction

Action and perception in infancy

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Abstract

In this introduction to the special issue on *Action and perception in infancy*, we summarize recent arguments of Milner and Goodale for a dissociation between vision for action and vision for perception in adults. We propose that this dissociation is probably present from birth, and further that vision for action and vision for perception follow different developmental trajectories. Based on this framework, we discern four themes of interest for infancy research (i.e., information and action, exploration and action, information and perception, and the interaction between action and perception) and introduce the contributions of the special issue accordingly.

Keywords: Action; Perception; Exploration; Information; Vision; Infancy

1. Introduction

A special issue on *Action and perception in infancy* should of course start with explaining what action and perception are about. After all, the development of action and perception and their relationship can only be understood in the context of an unambiguous description of action and perception. Such an unambiguous description, however, appears a mission impossible. Even a superficial glance of the contributions to this special issue, most of which

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are directly inspired by J. J. Gibson's (1979/1986) ecological approach, shows that there are almost as many descriptions of action and perception as there are contributions to this special issue. Our aim for the Introduction to the special issue on *Action and perception in infancy,* therefore, is a modest one. We summarize recent arguments of (Milner & Goodale, 1995) about the dissociation of vision for action and vision for perception), which we think can be reconciled with the ecological approach (cf. Michaels, 2000). As a logical extension, we further argue that action and perception may develop independently (cf. Atkinson, 2000; Bertenthal, 1996; Bertenthal & Clifton, 1998; Von Hofsten et al., 1998). These arguments will serve to organize and present the contributions to the special issue, and to introduce the developmental issues of interest that are dealt with in the special issue, some of which need, to our conviction, further attention from those studying the development of action and perception.

2. Action, Perception and Information

Atkinson, King, Braddick, Nokes, Anker and Braddick (1997) examined young children with Williams' syndrome (WS), a genetically based developmental disorder, posting a letter through a slot that could be varied in orientation (cf. Goodale et al., 1991). The children with WS showed less accurate performance as compared to their age-matched peers. However, when the children with WS were asked to match the orientation of the letter with the slot without posting it, performance was much more accurate and comparable to children without WS. In other words, children with WS are able to pick up information for matching the orientation of the postal slot, but they are not, however, able to use that information to control the arm movement involved in posting the letter. These findings neatly illustrate the functional dissociation of the visual system for action and perception as advocated in the work of (Milner & Goodale, 1995; Goodale & Haffenden, 1998; Goodale & Humphrey, 1998; Goodale & Milner, 1992). These authors define action as the use of vision to control or guide movement, and perception as the use of vision for the creation of an internal representation of the world that can be used in the identification and recognition of objects and events (e.g., Goodale & Humphrey, 1998, pp. 206–207). The neural substrates for vision for action and vision for perception are claimed to be distinct: the dorsal stream mediates the use of optical information for the control of movement, while the ventral stream supports the pick up of optical information to identify and recognize objects and events. Hence, (Atkinson's et al., 1997) suggestion that in children with WS the decrement in posting performance, but not in matching the orientation of the slot, points to a deficit in dorsal stream processing.

Thus far, we have used Milner and Goodale's terminology. However, as emphasized by (Michaels, 2000) there is a distinctive computational and representational flavor in their descriptions of action and perception, which clearly departs from the usage by ecological psychologists. Take, for instance, the concept of information that has a rather specific meaning within the ecological approach. Milner and Goodale argue that the ventral system *encodes* optical information to create viewpoint-independent or allocentric *representations* of the world: a clear example of an enrichment theory where, during the process of perception, meaning is assigned to impoverished information. The concept of impoverished

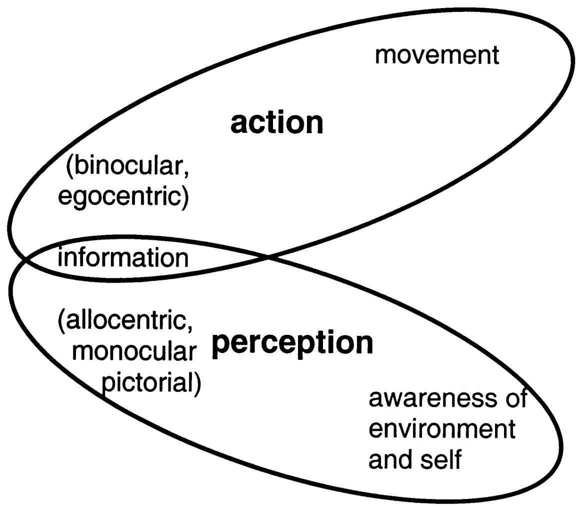

Fig. 1. A schematic representation of action, perception and information.

information can also be traced in Milner's and Goodale descriptions of action. The dorsal system is thought to *transform* optical information in viewpoint-dependent or ego-centric coordinates. This impoverished notion of information sharply contrasts with the idea that information is specific to the objects and events in the environment or directly guides movement, and hence, that there is no need for processing. Perception and action are direct.

Notwithstanding this and other conceptual differences with ecological psychology, we agree with Michaels that there is a lot to gain by accepting a separation between action and perception (Van der Kamp, Savelsbergh & Rosengren, 2001). Hence, we endorse the view that vision for action and vision for perception may indeed be functionally dissociated (cf. Fig. 1). Vision for action will be considered as goal-directed movements (e.g., walking, grasping, sitting etc.) that are lawfully controlled by optical information (cf. Michaels, 2000). We will shortly refer to this as the 'information-based control of movement'. Vision for perception[1] on the other hand is defined as the pick up or detection of optical information that leads to awareness or explicit knowledge of the environment and the self. It is important to emphasize that information and not perception is an integral part of the control of movement (i.e., action). As Michaels argues there is no 'between thing' (i.e., perception) in action, optical information directly guides the movement. In other words, it is not perception and action that get coupled, but information and movement. Similarly, it is not action, but movements that are indispensable for perception–as for instance Johnson and Johnson (this issue) demonstrate for eye-movements in object perception in 2- to 4-month-old infants.

3. Action and perception in infancy

Given the functional and structural dissociation between vision for action and vision for perception in adults, the logical question is about its origin and development. First, it may be that vision for action and vision for perception are dissociated from birth, and consequently, that both follow more or less different developmental trajectories. Alternatively, one could hypothesize that at birth vision for action is not dissociated from vision for perception, and hence, that development should be characterized as a process of differentiation (cf. Netelenbos, 2000). Although direct experimentation to test these alternative hypotheses has only started very recently (e.g., Berthier et al., 2001; Von Hofsten et al., 1998), a selective review of the literature suggests that in infancy vision for action and vision for perception are separate and develop independently. For instance, the study reported by Jouen, Lepecq, Gapenne, and Bertenthal (this issue) convincingly demonstrates that 3-day-old infants adjust their backward head movements to optic flow velocity. That is, newborn infants are sensitive to velocity when it concerns the information-based control of head movements. In contrast, studies assessing infant perception, which commonly use habituation or preference looking methods, found no sign that infants younger than 2 months of age perceive velocity (e.g., Dannemiller & Freedland, 1989, 1991; Wattam-Bell, 1990). This discrepancy between action and perception in the use of velocity information suggests that vision for action and vision for perception develop independently. The same conclusion presses itself forward with respect to information that is specific to the direction of motion: newborns direct their arm movements to a moving toy (Von Hofsten, 1982) but are not able to perceptually distinguish (i.e., do not dishabituate) different directions of motion (Wattam-Bell, 1996a). Moreover, (Von Hofsten et al., 1998) showed that 6-month-olds predict linear object motion when reaching, whereas they fail to extrapolate object motion in preferential looking tasks (Spelke et al., 1994). More recently, (Berthier et al., 2001) observed that nine-month olds often visually tracked and reached for a rolling ball even when the track was blocked by a barrier, whereas 5-month-olds were shown to perceive that objects do not move through the space occupied by other solid objects (Baillargeon, Spelke & Wasserman, 1985). Together, these observations suggest but do not prove that vision for action and vision for perception are already separate in the first few months after birth and develop independently, that is, the development of action and the development of perception follow different trajectories.

However, it should be realized that comparing action and perception studies has its pitfalls. First, since the infants' behavior is rather context-bound, the experimental settings need to be quite similar before a valid comparison can be made. Clearly, velocity information generated by peripheral optic flow presented by a sequence of lights in a dark room (Jouen et al., this issue) is quite different from velocity information specified centrally by moving targets displayed on a computer monitor (e.g., Wattam-Bell, 1990). And the optical information provided by a ball rolling on a track with a barrier (Berthier et al., 2001) may not be quite the same as the information generated by a screen falling on a solid box (Baillargeon et al., 1985). Hence, apart from other important dissimilarities, it is in particular the possible difference in the available sources of optical information that makes a direct comparison of these studies hazardous.

The second pitfall is the reliability of an exclusively age-based comparison. Given the large within and between subject variation that characterizes infancy research, and additionally, the uncertainties in establishing the age of onset for a particular behavior (e.g., Thelen & Smith, 1994), a comparison between the age of onset from disparate studies should be treated very carefully. Hence, more rigorous experimentation is needed before we conclude that vision for action and vision for perception are separate from birth and develop independently.

4. A research guide

One of the great advantages of the work of Milner and Goodale is that it provides a 'guide' for assessing the dissociation between vision for action and vision for perception (Rossetti & Pisella, 2001). This experimental framework is not dependent on age-based comparisons, and therefore, may be helpful in infancy research as well. We will not give an comprehensive account, but pick out a few points that can be brought in line with ecological thinking (cf. Michaels, 2000). The most fruitful avenue, we propose, is a distinction in terms of the type of optical information that is used and the way optical information is used in action and perception.

To start with the type of optical information, the distinction between egocentric or viewer-dependent processing for action and allocentric or world-centered processing for perception (e.g., Creem & Proffitt, 2001; Milner & Goodale, 1995; Norman, 2001) can be transformed into a distinction based on what optic information is used. On the one hand, movements are primarily guided by egocentric information, such as, object size in relation to hand aperture during grasping (e.g., Fagard, this issue). Perception, on the other hand, is more reliant on allocentric information, for instance, the relative size of one object in relation to a second one in case of judging object size. Consequently, assessing the relative importance of egocentric and allocentric information during infancy may shed light on whether action and perception develop separately. To be considered separate, manipulating egocentric information should have a larger impact on action than on perception, whereas the manipulation of allocentric information should have a larger influence on perception. Wattam-Bell (1996b in Atkinson 2000), for instance, demonstrated that the earliest perception of direction of motion after 10 weeks of age is exclusively based on relative motion information, that is, the direction of a target in relation to its background. It was several weeks later that infants were able to differentiate direction of motion on basis of the absolute direction of motion of the target without a background (i.e., egocentric information). In contrast, Von Hofsten (1983, p. 84) has argued that in early reaching '. . . the infant reaches in reference to a coordinate system fixed to the moving object instead of to a static background', that is, egocentric information. Of course, a decisive conclusion requires manipulating the background during infant reaching. Together, though, these studies show the potential of obtaining insight in the issue of a dissociation between vision for action and vision for perception during infancy by assessing the roles of egocentric information and allocentric information in early action and perception. It needs to be emphasized that a distinction based on either egocentric or allocentric information should not be interpreted as absolute. Although egocentric information may appear to be more important in the control of movement, that is not to say that allocentric information is not involved at all (cf. Creem & Proffitt, 2001). This is also true for the second information-based distinction that may serve as a fingerprint for the dissociation between action and perception in infancy. Recent investigations with a patient with visual form agnosia (DF) and healthy subjects have shown that perception is more reliant on the detection of monocular pictorial invariants (e.g. shading, texture relative size), whereas binocular (e.g. disparity and vergence) and monocular kinematic invariants (e.g. optic flow) appear to be more important in action (Marotta, Behrmann & Goodale, 1997; Mon-Williams et al., 2001; Norman, 2001). Like the distinction based on ego- versus allocentric information, the differential role of binocular and monocular kinematic information versus monocular pictorial information is perhaps useful in determining the dissociation between vision for action and vision for perception in infancy (cf. Kellman & Arterberry, 1998; Yonas & Granrud, 1985). Obviously, there is the problem of the lack of sensitivity to binocular information before 3.5 months of age (Fox et al., 1980; Held, Birch, & Gwiazda, 1980), although it should be noticed that these observations are almost exclusively derived from perception studies only.

An applicable distinction of the way optical information is used, is the different time scales at which information operates in action and perception (Michaels, 2000). The information-based control of movements is essentially on-line, that is, in the here and now. The use of information for perception, in contrast, is much less time-dependent: it refers further into the past or future. The on-line character of action is neatly demonstrated in pantomimed prehension or reaching to remembered objects (Goodale, Jakobson & Keillor, 1994; Westwood, Chapman & Roy, 2000), where optical information specifying object size, distance etc. is not available at the moment the reach is performed. The reorganisation of the reach observed in these situations (i.e., movement duration increases, peak velocity is lower and the number of movement units increases) demonstrates the 'on-line' character of action. Moreover, like perception and contrary to 'normal' reaching, pantomimed prehension is shown to be subject to optical illusions (Westwood, Chapman & Roy, 2000). These changes in movement kinematics are thought to reflect the involvement of the ventral system in movement control. That is, when the action system is not capable of bridging the temporal delay, the control of the movements shifts to the ventral system (Creem & Proffitt, 2001; Milner & Goodale, 1995; Norman, 2001). These studies may serve as a further example to assess the contribution of the two visual streams in action and perception during infancy as well. That is, recording movement kinematics after introducing a delay or removal of information may provide a window into whether and how dorsal and ventral systems interact during infancy, and how this interaction may develop. Reaching in the dark (e.g., Clifton et al., 1994; Hood & Willats, 1986) or intercepting moving objects that are temporally occluded by a screen (Berthier et al., 2001; Van der Meer, Van der Weel, & Lee, 1994) are potential paradigms in this respect.

5. Contents of the special issue

At first sight, the eighteen contributions in the present special issue on *Action and perception in infancy* cover a very broad and diverse range of topics; from the timing of a eye blink, to vocal play, postural control, eye movements in the development of the perception of object unity, to the role of attention in the development of action and perception and so on. As diverse as they seem, the contributions obviously share common themes. These themes become particularly clear in relation to the arguments presented above. We have argued that vision for action and vision for perception are dissociated during adulthood. Subsequently, we have suggested that such a dissociation is present during infancy as well. Although this is still an empirical issue, this putative separation between action and perception in infancy will be used here to organize the contributions. Hence, the special issue is divided in sections that deal with action, perception, and the interaction between action perception in infancy. In what follows, we will shortly introduce these sections on *Information and action, Exploration and action, Information and perception,* and *Action and perception,* and pinpoint the respective issues of interest on basis of the empirical and theoretical contributions made to the present issue.

The first section, *Information and action,* consists of studies that examine action in infancy. Generally speaking, the contributions in this section deal with the information-movement coupling (and importantly from our analysis, not with perception-action coupling). Considerable progress has been made in identifying the optical information that is coupled to movement for numerous actions in adults. To name just a few examples; motion parallax to control postural sway during walking (Bardy, Warren & Kay, 1996), and the rate of expansion and disparity to control the timing of interceptive actions like punching and catching balls (Bennett et al., 1999; Michaels, Zeinstra, & Oudejans, 2001; Van der Kamp et al., 1999). Knowledge about the optical information involved in infants' actions, however, is not abundant, perhaps with the exception of postural control (e.g., Bertenthal, Rose & Bai, 1997). This is unfortunate, because being able to use optical or other information to guide movement is a necessary, but not sufficient condition for adaptive action also in infancy. It is only after researchers have identified what information contributes to infants' goal-directed movements, that more insight will be obtained in possible processes underlying the development of action such as, for instance, the selection of different information or changes in the way information gets coupled to movement. The section *Information and action* reflects the researchers' awareness of the importance of these empirical challenges. The contributions seek to explain the adaptedness of infants' actions in terms of the information that is used to guide movement. To this end, different levels of analysis are used, ranging from an evaluation of whether actions are indeed adapted to the properties of the environment (Corbetta, Thelen & Johnson; Fagard; Fetters et al.; Kingsnorth & Schmuckler), via the effects of visual perturbations on movement control (Barela; Godoi, Freitas Júnior, & Polastri; Bertenthal, Boker, & Xu; Jouen et al.) to the identification of the specific optical invariants that get coupled to the movement (Kayed & Van der Meer). Notice that, consistent with our arguments, it is foremost egocentric information or viewer-dependent information that is manipulated in these action studies. To assess the coupling between peripheral optic flow and head movements, for example, Jouen et al. removed all allocentric information by darkening the lab. And in their investigation of infant eye blinking, Kayed and Van der Meer had infants seated 40 cm in front of a huge sheet such that only the egocentric expansion patterns projected on the sheet were available. Together these studies demonstrate that the evaluation of the type of optical information that is used and how that information is used to control movement can, at least partly, provide an explanation of the particulars of infants' actions and age-related changes therein. Some contributions, however, rightly emphasize that information should not be interpreted as the single cause in the development of action (cf. Corbetta et al.; Kingsnorth & Schmuckler).

The section on *Information and action* starts with an examination of the timing strategies in defensive eye blinking to optical collision. Kayed and Van der Meer found in a group of 5 to 6 month old infants that the blink is controlled by a threshold optical angle of the image of a virtual looming object. The use of this specific optical invariant, however, appears to lead to difficulties in the case of accelerative collision courses. These difficulties were not present in the 6 to 7 month old group of infants, who were shown to use time-to-collision information. Hence, infants shift to a more sophisticated timing strategy by selecting a different optical invariant that allowed them to deal not only with constant velocity, but also with accelerative collision courses. The next three contributions examine the use of global flow information in postural control. Jouen et al. investigated 3-day-olds that were presented with backward peripheral optic flow that moved at different constant velocities. Their observations showed that the infants not only responded by moving their head backwards, but also that the magnitude of infants' head movements was linearly related to optic flow velocity. Barela et al. examined the coupling between optical information and trunk sway in 6 to 9 month old infants as they acquire sitting. The results revealed that trunk sway was related to the frequency of back and forward oscillations of the moving room, although the nature of the coupling, as indicated by measures of coherence and gain, differed for the two frequencies. Perhaps surprisingly, no developmental change was found in the coupling between global flow and trunks sway. Bertenthal et al. report a similar experiment with 9-month-olds sitting in a moving room with the walls oscillating at different frequencies. Postural sway was assessed through multiple measures including center of pressure (COP) and head and lower back movements. Postural sway was influenced by the driving frequency of the walls of the moving room. However, the relation between the three measures of postural sway and the room movements, indicated by coherence, did not reveal the same pattern. Not unlike Barela and colleagues, these authors conclude that development of postural control consists of an increasing coordination and faster anticipation of perturbations, but without any significant changes in the underlying dynamics. The key to this conclusion, according to Bertenthal et al., is insuring that the same measures are used at different ages. Fagard investigated the development of reaching and grasping in 5- to 12-month-olds as they relate to object size. She observed that starting from 7 to 8 months of age infants tended to reach with two hands for large objects, but only at 11 to 12 months they did so consistently. Like in reaching, the first adjustments of the grasp (e.g. hand aperture) to the size of the object occurred at 7 to 8 months but increased in accuracy much more rapidly. Corbetta and co-workers examined 5 to 9 months old infants as they reached and grasped objects of different sizes and textures. It was found that, like in Fagard's study, before 8 months infants do not consistently adjust the reach and grasp to the properties of the object. Based on these findings Corbetta et al. argue that only when the early motor constraints disappear infants are able to use optical and haptic information to adapt their actions to objects. That is, infants' actions cannot always be simply explained by the scaling of body size to environmental measures. A similar conclusion is reached by Kingsnorth and Schmuckler who report on 14 to 30 months old toddlers' increasing ability to cross barriers. The authors' aim was to examine the role of body size, walking skill and locomotor experience in the infants' ability to cross barriers of different heights. They found that barrier crossing was most strongly related to locomotor experience, and not to walking skill as indexed by footprint analysis of gait or to body size measures such as leg length. Finally, Fetters et al. assessed limb and head movements in the presence of rhythmic acoustic and optical information generated by a rattle, during a face-to-face interaction with the examiner, and when no optical and acoustic information was present in healthy infants and infants that were exposed to cocaine in-utero. Results show that the rattle condition elicited a different movement organization compared to the other conditions. Cocaine-exposed infants in particular appeared differentially sensitive, as indicated by the measure of coherence, to the acoustic and optical information generated by the rattle.

The second section *Exploration and action* assembles studies that focus on the importance of exploration in action. Like action and perception, exploration is a thorny concept. Putting all possible ambiguities aside at once, in the context of action as it is defined here exploration may serve at least two functions. First, exploration can be thought of as refining existing or finding new information-movement couplings. The second function can be loosely defined as the active gathering of information that is relevant for choosing between future actions, that is, to discover the affordances of the environment.

To start with the first, exploratory behavior is perhaps the key process in establishing the relation between information and movement. In her early work, (Thelen, 1979) provided a detailed account of a large variety of rhythmical and stereotyped behaviors in healthy infants in naturalistic settings, and found that the onset, peak performance and decline of these behaviors highly correlated with the development of action. It is intriguing to speculate that these apparently stereotyped head banging, rocking, kicking, arm waving behaviors represent the active probing of the relationship between multiple sources of information (e.g., vision, proprioception, audition) and the movements made. Several issues need to be dealt with, however, before decisive answers can be given. First, are these supposed exploratory movements a prerequisite in the development of early actions like reaching, grasping sitting, locomotion etc.? Or, if exploratory movements can be elicited earlier or more frequently, how does this effect the forming or refining of information-movement couplings? How are exploratory movements organized, and what characteristics make them work (e.g., repeatability, specificity, variability etc)? And finally, how does exploration itself change with development? Some of these issues are touched upon in three contributions of this section that consider exploration in the context of establishing and refining information-movement couplings. Metcalfe and Clark, for instance, examined infants while standing quietly either hands-free or while lightly touching a contact surface. Based on their findings, the authors argued that infants use the information from light touch for multiple purposes in the development of upright stance. The observed reduction of sway amplitude in the upper body demonstrates that light touch stabilizes postural sway. Second, the uncoupling between head, shoulder and center of mass, which was indicated by decreased cross-correlations and increased variance of the time lag of the cross-correlations, indicates that light touch elicits exploration of different patterns of postural coordination. According to Metcalfe and Clark, the infants use haptic information from light touch to tune the relation between information from the ankle joint proprioceptors and from the visual and vestibular systems for developing postural control in upright stance. Also Olmos and Alto interpreted increased variability as exploration. These authors analyzed how 10 and 24 month old infants modulate force to pull a ring that activates an attractive doll. Four different force requirements were used. The finding that the older infants showed a larger variation in the force produced when pulling the ring was interpreted by the authors as exploration of the pulling action. This exploration enabled the older infants to deal more flexibly with changing circumstances, that is, they adjusted their pulling behavior must faster when the task requirements increased. Goldfield examined whether, during production of vocal sequences compared to those produced singly, 6 month old full term and preterm infants explored the relation between tongue height and tongue advancement, as measured acoustically by the first formant (F1) and second formant (F2) frequencies, respectively. It was found that the production of vowels in sequence, in contrast to individual vowels, was restricted to specific regions of vowel space (i.e, F1-F2 space). Goldfield argues that this reflects a strategy where acoustic information is used to temporally gather together muscle groups into functional units. Moreover, he argues that repetitive vocalizations, that is, vowels produced in sequences tend to impose organizational constraints on the exploration of the vowel space.

The second function of exploration, the active gathering of information relevant for choosing between future actions, is eloquently presented in the work of E.J. Gibson (for overviews see Gibson, 1988; Gibson & Pick, 2000) and more recently in that of Adolph (e.g., 1997) on the development of perceiving affordances for locomotion. These and other researchers have described in detail the exploratory behaviors that infants use to choose the most suitable among different actions. They convincingly showed that exploration is dependent on the action skills of the infant. For instance, compared with a standard rigid surface a deforming surface elicits different and more exploratory behaviors in walkers, but not in crawlers to decide whether the surface is traversable (Gibson et al., 1987). In their contribution Adolph, Eppler, Marin, Weise, and Wechsler-Clearfield argue that what is missing, however, is a mechanistic account of the process of exploration in infant locomotion. To provide such an account Adolph et al. review previous work and distinguish three types of exploratory behaviors; exploration from a distance, exploration via direct contact, and exploration of alternative means. The authors propose that these exploratory behaviors represent different phases within the sequential process of exploration. Each phase in the sequence is a process of obtaining progressively more information leading to a decision about action.

Notice that this second function of exploration is closely related to perception, in particular the perception of affordances. An important difference is, however, that in case of exploration for action, infants gather knowledge about the possibilities for action[2], whereas perception, as we defined it, is directed at obtaining knowledge about the environment and the self. To this we turn in the next section.

The third section *Information and perception* presents studies that deal with infants' perception of the environment (Johnson & Johnson; Smitsman & Schellingerhout; Rader & Vaughn) and the self (Rochat & Striano). Research of the last two decades employing habituation and (forced choice) preference looking techniques have provided extensive knowledge on hitherto unforeseen perceptual capacities in infants. We now have detailed descriptions about the onset and development of the perception of object properties like unity, segregation, solidity, size, shape, substance, color and so on. Moreover, there is a growing body of knowledge about the sources of optical information, in particular allocentric information, that infants pick up to perceive these object properties. For instance by 4 month of age infants use motion, edge orientation, shape, depth and color in the perception of object unit (Johnson & Johnson; for extensive reviews of research in the development of perception the reader is referred to Gibson & Pick, 2000; Kellman & Arterberry, 1998). The current debate in the field of perceptual and cognitive development focuses on the mechanisms of the development. Spelke (e.g., 1998), for instance, holds the view that perception of object properties develops by enrichment around a set of innate core principles (e.g. continuity but not inertia). Others (e.g., Johnson & Johnson) argue, much more in line with the ecological approach, that the development of perception is process of differentiation. Infants learn to visually scan the optic array and to scrutinise the information that specifies the object properties. It is foremost this active or exploratory nature of the development of perception that is being emphasized in the contributions of this section on *Information and Perception.*

Johnson and Johnson investigated the scanning strategies used by 2- to 3.5-month-old infants in the now classical rod-and-box habituation paradigm (cf. Kellman & Spelke, 1983). A corneal reflection system was used to record infants' eye movements. Results indicated that scanning styles were specific to display characteristics. The infants engaged in more extensive scanning when a wide occluder or misaligned edges challenged unity perception. In addition, older infants tended to scan the lower parts of the displays more frequently than did younger infants. Johnson and Johnson argue that these observations are consistent with the view that self-directed eye movements are critical in the development of the perception of object unity. Smitsman and Schellingerhout examined haptic perception of the layout of the environment and way finding in congenitally blind infants and toddlers. Compared to sighted infants congenital blind infants show little outer directness. Smitsman and Schellingerhout devised a surface with a textured gradient that can be perceived by touch. They show that 8 to 20 month old infants increase the amount of exploration when presented with these surfaces, and in addition that compared to a surface that contained homogeneously distributed texture elements the surface with the texture gradient improves way finding in blind 4-year-olds. Rochat and Striano review studies and present some new findings that show that at least from 2 months infants become increasingly aware of their own body. They argue that this development of the perception of the self, or implicit sense of self, is rooted in the intermodal exploration of their own movements like kicking, sucking or bringing the hand to the mouth. Rochat and Striano view proprioception, in conjunction with other senses, as the modality 'par excellence' in the development of the perception of the self. The final contribution of Rader and Vaughn measured the amount of arm extensions (an indicator of perception and not movement control!) before and after tasting a sweet or bitter object in 2 to 6 month old infants. In the absence of information specifying the taste (denoted as a hidden affordance), infants reached more after tasting the object when it had been discovered to be sweet and less when they found its taste to be unpleasant. Infants, therefore, differentiated between the objects, even when the affordance is specified by information that is not available at the time of action.

When separating vision for action and vision for perception, the issue that naturally emerges is that of the relation between the two in infancy. It is this relation that is discussed in the final section *Action and Perception.* This relation can be dealt with in developmental and real time. Instigated by Piaget's work, the relation between action and perception (continuous with cognition (cf. footnote 1)) on a developmental time-scale has been one of the major challenges in infancy research. Today, at least two lines of thoughts have revitalised thinking on the developmental relation between action and perception. First, the ideas articulated by Thelen (2000; Thelen & Smith, 1994) on the developmental origins of the embodied mind. In short, Thelen argues that cognition is embodied, that is to say, that it arises from dynamic and flexible bodily interactions with the world throughout life. The second line of thought follows from the work of Milner and Goodale. The argument is that action and perception follow different developmental trajectories, but do surely interact during development (Atkinson, 2000; Bertenthal, 1996; Rochat, 2001). Straightforward predictions about the developmental relation between action and perception, however, are not easily deduced from Milner and Goodale's framework. Therefore, establishing when and how action and perception interact during the process of development is an important theoretical and empirical future challenge. In his contribution Bremner examines the developmental relationship between action and perception in infancy by reviewing studies that relate to search errors observed in A-not-B tasks. Bremner's analysis seems reconcilable with the framework offered by Milner and Goodale. He argues that infants are born with structures that permit a basic undifferentiated awareness of properties of the environment. These structures support direct perception of the world and lay the foundation for physical knowledge emerging later in infancy. Action, according to Bremner, initially develops independent from this early undifferentiated perceptual awareness. Studies that examine the search errors in A-not-B tasks illustrate this point; infants appear to be aware of where the object is, but are not able to use this information to search (prior to 8 months) or to redirect their search to a new location (after 8 months). Bremner further argues that action itself serves to refine perceptual awareness and eventually becomes linked directly to physical knowledge.

The relation between action and perception in infancy can also be assessed in real time. We alluded to this possibility in our discussion of the different time scales at which action and perception operate. An investigation of the kinematics of infants' arm movements when reaching in the dark (i.e., removing all optical information) or reaching for moving objects that are temporally occluded (i.e., creating a delay between information and movement), we suggested, may provide a window into the interaction between vision for action and vision for perception. Of course, the development of this interaction, that is, the changes of this interaction that occur with age need to be described as well. A second posibility to investigate the development of the interaction between action and perception in real time would be the use of attention demanding tasks where action interferes with perception or vice versa (cf. Berthier et al., 2001). Boudreau and Bushnell's observation of what they denote the 'attention driven cognition-action trade off' neatly illustrates this point. The authors report two experiments with 9- to 11-month-olds that show that perceptual discrimination becomes compromised when attention is primarily directed to adjust reaching movements to environmental demands. And conversely, that the organization of reaching movements become compromised when attention is directed to perception of (or thinking about) the goal of the action. These findings emphasize the importance of the allocation of attention as a potential factor in the development of the relation between action and perception (and cognition) in real time.

Notes

1. Gibson (1979/1986, p. 258) argued that "the theory of information pickup makes a clear-cut separation between perception and fantasy, but it closes the supposed gap between perception and knowledge. The extracting and abstracting of invariants are what happens in both perceiving and knowing. To perceive the environment and to conceive it are different in degree but not in kind. One is continuous with the other." Hence, when we refer to 'perception', this should be taken to mean 'perception as continuous with cognition' in the Gibsonian sense.
2. (Decety and Grèzes 1999) suggested that dorsal stream but not ventral stream activity is involved in the perception of action, but only if that action had to be imitated. It is tempting to speculate that this also true in the case of exploring what the environment affords for action.

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